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Title: Paradigm shifts in abdominal aortic aneurysm management based on vascular registries

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Abstract

Abdominal aortic aneurysm (AAA) is a relatively common and potentially fatal disease. The management of AAA has undergone extensive changes in the last two decades. High quality vascular surgical registries were established early and have been found to be instrumental in the evaluation and monitoring of these changes, most notably the wide implementation of minimally invasive endovascular surgical technology. Trends over the years showed the increased use of endovascular aneurysm repair (EVAR) over open repair, the decreasing perioperative adverse outcomes and the

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early survival advantage of EVAR. Also, data from the early EVAR years changed the views on endoleak management and showed the importance of tracking the implementation of new techniques. Registry data complemented the randomized trials performed in aortic surgery by showing the high rate of laparotomy related reinterventions after open repair. Also, they are an essential tool for the understanding of outcomes in a broad patient population, evaluating the generalizability of findings from randomized trials and analyzing changes over time. By using large scale data over longer periods of time, the importance of centralization of care to high-volume centers was shown, particularly for open repair. Additionally, large-scale databases can offer an opportunity to assess practice and outcomes in patient subgroups (e.g. treatment of AAA in women and the elderly) as well as in rare aortic pathologies. In this review article, we point out the most important paradigm shifts in AAA management based on vascular registry data.

Keywords: “Abdominal aortic aneurysm” “Endovascular Aortic Repair” “Paradigm shifts” “Registry” “Quality improvement” “database”

Introduction:

Abdominal Aortic Aneurysm (AAA) is a major cause of mortality as a result of aneurysm rupture.[1] With an aortic aneurysms prevalence of 6% in males, the health burden of AAA is substantial.[2] However, a better understanding of aneurysmal disease, earlier detection, the introduction of minimally invasive endovascular aneurysm repair (EVAR) and increasing experience have improved outcomes for patients with AAA. Therefore, the management of AAA has changed radically over the years and is in constant evolution.

The management of AAA has been extensively studied and guidelines have been established by the European Society for Vascular Surgery (ESVS) and the Society for Vascular Surgery (SVS).[3,4] These recommendations are founded on Randomized Controlled Trials (RCT), prospective data and retrospective studies. Although RCTs are considered the gold standard in evaluating the effectiveness of a treatment, it is important to understand their inherent limitations.[5] Strict inclusion and exclusion criteria and high costs can limit the external validation and generalizability of the results. Also, the study setting and conditions, with specific surgeons and centers performing operations on selected patients might not relate to broader clinical practice. In times where technique, technology and experience improve rapidly, RCT results might no longer reflect contemporary practice by the time they get published. Furthermore, at the time of early RCTs, when the new technology was introduced, long-term behavior, complications and their treatment were largely unknown and may have affected the results. Thus, RCTs cannot be used to answer every clinical question. Also, existing RCTs may be underpowered to detect differences for outcomes with low event rates. Vascular registry data can complement RCTs and are an essential tool for the understanding of outcomes in a broad patient population, evaluating the generalizability of RCT findings, rapid assessment of new technology and procedures, and analyzing changes over time. Registries offer data for large-scale outcome analysis, over longer periods of time and in multiple regions, countries or continents, enabling continuous assessment and improvement of AAA management.

Registries are defined as an organized system that collects uniform data through observational study methods to evaluate outcomes for patients defined by a disease or exposure, for a predetermined purpose.[6] The first formal vascular registry was created by DeBakey and Simeone during the World War II with a subsequent review of more than 2000 vascular injuries.[7] Their observations on the treatment of vascular injuries with ligation showed high amputation rates. However, alternative management strategies were investigated and showed poor outcomes.[7] These data caused arterial ligation to become the United States (US) Army policy.[7] During the Korean War, Dr. Carl Hughes showed an important decline from the 49% amputation rates in World War II to 13% in the Korean War.[8] The outcomes in the Korean War registry emphasized that revascularization should only be attempted within eight hours of injury. With the implementation of Medicare in the US in 1965, collection of its administrative data started. Medicare is a federal health insurance program for individuals in the US who are aged ≥65 years and selected younger individuals with disabilities or end-stage renal disease, and in 2015 over 55 million beneficiaries were covered. These data have been essential for providing real-world evidence among older individuals in the US. In 1966, Dr. Norman Rich established the Vietnam Vascular Registry (VVR) which contains information from over 7500 patients. The long-term follow-up of this database provided insight in the long-term outcomes of these revascularizations.[9,10] Data collection by National Inpatient Sample (NIS) started in 1988 and includes a stratified 20% random sample of all nonfederal inpatient hospital admissions throughout the US.[11] When used with adequate weighting, this database represents nearly 95% of all inpatients admissions in the US. The Vascular Study Group of New England (VSGNE) database was created in 2001 by Jack Cronenwett in New England and was followed by the launch of the Vascular Quality Initiative (VQI) by the Society for Vascular Surgery (SVS) in 2011. The VQI was designed to improve the quality, safety, effectiveness, and cost of vascular surgery and reports quality measures to physicians and hospitals.13

In Europe, the predecessor of the Swedish Vascular registry (Swedvasc), the Vascular Registry in Southern Sweden (VRISS) was established in 1987 by Sven-Erik Bergentz, David Bergqvist, Thomas Troëng, Eibert Einarsson and Lars Norgren and gained national coverage in 1994. This first population-based registry in vascular surgery has been an essential data source for research and enabled important quality improvement projects. In England, the Hospital Episode Statistics (HES) database was established in 1989 and collects information about all patients admitted to National Health Service hospitals in England.[11] The European Collaborators on Stent-Graft Techniques for Abdominal Aortic Aneurysm Repair (EUROSTAR) registry was established in 1996 and has tracked the implementation and evolution of EVAR. In 1997, as demand for a collaborative dataset to compare vascular surgical practice in different countries rose, Vascunet, a combination of European and Australasian national and regional vascular registries, was created. In 2014, a collaboration of Vascunet, the SVS VQI and manufacturers formed the International Consortium of Vascular Registries (ICVR), combining existing vascular quality improvement registries from in America, Europe and Australasia.[12] An overview of the administrative datasets and quality improvement registries employed in vascular surgical research is provided in Table 1.

Quality improvement, administrative, and combined databases have specific limitations due to their distinctive designs. While quality improvement databases, such as the Swedvasc and the VQI, have the advantage of clear variable definitions and granularity, the voluntary basis of these registries could cause potential bias and long-term follow-up is often limited. Administrative data, such as HES, Medicare or NIS, offer large patient numbers and often national coverage. However, inconsistency in coding systems and limited details are inherent limitations. Combination databases, such as Vascunet and ICVR, contain large patient numbers and geographic variation but are limited due to the heterogeneity of the databases they combine.

In this review we describe the most important paradigm shifts in abdominal aortic aneurysm management originating from vascular registry studies. We will also describe potential future breakthroughs. Eligible manuscripts were based on registry data including quality improvement, administrative and combined databases.

The shifting dominance and decreasing perioperative adverse outcomes of EVAR

The large patient samples and data collection over long periods of time make registry studies ideal sources for studying trends over time. Several registry studies spanning the previous four decades enabled the evaluation of the shift in utilization of EVAR and open surgery and showed the decreasing adverse outcomes over time. A study covering the last two decades of the 20th century showed no decrease in mortality after elective and ruptured AAA open repair (average operative mortality over the study period in elective repair: 5.6% and ruptured repair: 45.7%).[13] However, at the end of the 20th century, a shift in the treatment paradigm was observed as EVAR was increasingly utilized.[14] This trend was accelerated in the first decade of the 21st century, with EVAR use surpassing open repair in 2005 for elective surgery and the increasing dominance since (5.2% EVAR utilization in 2000; 74% EVAR in 2010).[15] Decreasing 30-day mortality rates were observed for endovascular repair despite the higher age and rates of comorbidities in the patients undergoing EVAR compared to open repair (Between 1994 – 1999: 3.4% 30-day mortality after EVAR and 1.1% between 2012 - 2016)(Table 2).[14,16,17] With the increasing expansion of EVAR use, overall operative mortality for elective AAA repair declined (4.9% in 1995 to 2.4% in 2008).[18] These findings proved that the results of randomized controlled trials were generalizable to the US population and justified the increased use of EVAR despite its higher costs, making it the preferred management for AAA repair with adequate aneurysm morphology.

EVAR survival advantage and the importance of late outcomes and follow-up

When looking at long-term survival in registry studies, the survival advantage after EVAR compared to open repair persisted for approximately three years, after which it was similar to survival after open repair.[17,19] In RCTs, with smaller patient populations, younger patients, and restricted inclusion criteria, this survival advantage with EVAR persisted for shorter periods of time.[20–22] Also, this study confirmed that late rupture rates are higher after EVAR compared to open repair (5.4% after EVAR and 1.4% after open repair, through eight years of follow-up).[17] These finding highlighted the importance of performing long-term follow-up after intervention. In terms of late reinterventions after AAA repair, analysis of Medicare data confirmed the RCT results showing higher aneurysm related reinterventions after EVAR compared to open repair (18.8% vs 3.7% at eight years), but for the first time also showed the higher rate of laparotomy related complications of hernia and bowel obstruction after open repair (8.2% after EVAR, 17.7% after open repair at eight years). This analysis prompted the RCT PIs to try to go back to find laparotomy related complications in the randomized patients as best as they could and these were reported subsequently.[19]

Registry studies using long-term follow up data also show the low annual imaging follow-up adherence after EVAR with less than half of the patients receiving follow-up five years after EVAR.[23,24] Also, loss to follow-up was highest in patients undergoing urgent repair (HR: 1.27 (95%CI 1.20-1.35).[23] Despite the low costs of ultrasound surveillance, follow-up imaging still primarily occurred through CT surveillance (with a decrease between 2002 and 2010 from 60.8% to 42.1%).[25] These studies showed alarming trends and important opportunities for quality improvement.

Centralization of open AAA surgery

The complexity of AAA repair procedures might warrant the centralization of these procedures to high-volume centers and by high-volume surgeons. In registry data from 2001-2003, the highest-volume centers used an endovascular approach 44% of the time compared to 18% EVAR use in the lowest-volume centers.[26] Also, ICVR data showed a clear increase in survival after open repair in higher-volume centers with 2.4% difference between the highest- and lowest-volume centers (Figure 1).[27] However this relationship was not evident in patients undergoing EVAR, where a decrease in mortality was seen between the first- and second-lowest volume quintiles (2.5% vs. 1.6%), but little effect of increasing volume on mortality in the following quintiles.[27,28,29] Surgeon volume had a similar association with perioperative mortality after EVAR and open repair.[30,31] After EVAR, VQI data showed no effect of surgeon volume on perioperative mortality (Q1: 1.8% vs Q5: 1.6%). However, perioperative mortality after open repair decreased with increasing surgeon volume (Q1: 6.4% vs. Q5: 3.8%). For the treatment of rupture repair, Vascunet data showed that centers with higher volume or with a primary EVAR approach were associated with decreased perioperative mortality (Figure 2).[32] The strong relationship between center and surgeon volume with perioperative mortality after open repair shown in these registry studies impacted the recommendation that open surgery should be centralized to high-volume centers and surgeons.

Although perioperative death is a highly relevant quality indicator for open AAA repair, it may not be as appropriate for EVAR. EVAR can be considered as a minimally invasive procedure, and consequently has a minimal perioperative risk. Instead, there is a concern with long-term durability for EVAR. Therefore, the need for late reoperation and the risk of late ruptures could be more relevant quality markers for EVAR. This aspect needs to be incorporated into future analyzes aimed at studying the potential need for centralization of EVAR operations as well.

Understanding risk factors

Registry data provide a unique tool for understanding risk factors as they contain a real-life population and can be used for better preoperative patient selection. Risk calculators predicting mortality after EVAR and open repair included comorbidities, sex and age (Figure 3).[33–35] This enables physicians to better identify high-risk patients and to guide clinical decision making. For specific subgroups, such as elderly patients, registry data can also help in the selection of treatment eligible patients. A study using the VQI data showed that elderly patients in the highest risk strata still had 50% survival at five years and only comprised 4% of the elderly population.[36] Also, scoring systems based on registry data can help identify risk factors for specific complications.[37,38] For example, Swedvasc data identified patient-related haemodynamic risk factors together with surgical skill and decision making as risk factors for intestinal ischaemia in 1997.[36] Also, VQI data showed that cold renal perfusion was associated with a decreased risk of acute kidney injury if clamp time exceeded 25 minutes during open juxtarenal AAA repair (OR: 0.4 [95%CI 0.2-0.97]).[35] Thirdly, understanding risk factors for AAA development has created better selection possibilities for screening. Screening data from the Lifeline registry showed that smoking cessation and a healthy lifestyle were associated with lower risk for AAA.[39] These screening data also showed that a large sample of the patients with AAA are not screening eligible under the current criteria.[39] In Finish data, over a fifth of male patients would experience an AAA rupture before reaching the screening eligible age of 65 years. In male smokers this proportion was even higher with 31.7% rupturing before age 65 (Figure 4).[40] Revisions to the current screening guidelines using up-to-date registry data may potentially reduce these rates of rupture. Also, in the light of a decreasing prevalence of the disease the target group for AAA screening may need to be modified and more selectively target high risk groups, in order to maintain the effectiveness of screening programs.[41]

Endoleak management

After early aggressive treatment of endoleaks, EUROSTAR data showed that indication for reoperation should be dictated by aneurysm expansion.[42] The EUROSTAR registry was established in 1996 and collected data from patients undergoing infrarenal EVAR. The EUROSTAR data showed that persistent endoleaks, but not temporary endoleaks, were associated with sac expansion and late rupture.[43] These results highlighted the importance of screening for endoleaks after EVAR.[43] Eurostar data also showed that type I and III endoleaks had a significant negative impact on late rupture but not type II,[45] this latter fact was confirmed by others, although the true long-term significance of type II leaks is yet to be determined.[44,45] With these results, a better understanding of the natural history of endoleaks was achieved, hereby avoiding overtreatment by recommending routine follow-up for patients with type II endoleaks and reinterventions only in patients with sac increase. This showed the importance of following the implementation of new procedures with registry data and a decrease in re-intervention, primarily in coil embolization procedures (4.2% in 2001 – 2.5% in 2007), was subsequently noted after EVAR.

Treatment of elderly

Elderly patients are often excluded in RCT studies. However, this subgroup has been studied in registry data, showing that treatment of AAA is often performed in elderly patients, and that patients over 80 years with reasonable life expectancy and quality of life can undergo elective AAA repair with excellent outcomes. Also, the survival benefit of EVAR over open repair, which was shown using Medicare data, was most pronounced in older patients (67 to 69 years old: 2.1% absolute perioperative mortality difference; 85 years and older: 8.5% difference) (Figure 5).[19] Also, the increasing adoption of EVAR over the years was most dramatic in patients over age 80 and this age group also had the most dramatic reduction in deaths due to rupture.[18]

From the Swedvasc registry, it was found that the importance of age for short-term outcome after AAA repair has diminished,[46] and that octogenarians selected for AAA repair in fact had a superior long-term survival compared to the general population.[47] VQI data showed excellent survival in the majority of elderly patients after contemporary EVAR with only 4% of the elderly population in the highest risk strata.[36] These observations suggests that the observed change in indication that has occurred with the introduction of EVAR, with a dramatic increase in older patients being offered AAA repair in recent times, is so far a reasonable development.

Treatment of female patients

There are concerning sex discrepancies in AAA presentation, management, and outcomes that disadvantage female patients. As female patients are underrepresented in clinical trials, the natural history of AAA in female patients is not clearly defined. Analysis of vascular registry data showed that female patients are treated at older age (median age 75 vs. 72 years, P<.001) and at smaller diameters (57 vs. 59mm, P<.001).[48] Also, female patients undergo repair of rupture at smaller average diameters (71 vs. 79mm, P<.001) than men.[48] More female patients have hostile neck characteristics such as shorter and more angulated necks.[49] After intact repair, female patients have worse 30-day outcomes when undergoing EVAR (3.2% vs. 1.2%, P < .001) and open repair (8.0% vs. 4.0%, P = .04).[48,50,51] However, this early discrepancy in survival outcome diminished over time, and survival after EVAR was similar in female and male patients after approximately two years.[48] A vascunet-study has shown that the biggest difference in 30-day mortality between open surgery and EVAR is seen in females over 80 years of age, so elderly females benefit the most from EVAR compared to open surgery(1.3% vs. 9.7%).[51] As a specific aneurysm diameter generally represents a relative greater increase in aortic diameter in women than in men, diameter might not have the same predictive value in female patients as in males. Registry data were therefore used to study the impact of aortic size index, a measure indexing aneurysm diameter to body size. In female patients, the aortic size index was the most important determinant of aneurysm rupture, while aneurysm diameter alone was the most predictive determinant of rupture in male patients (Figure 6).[52] Also, in patients with a ruptured AAA in Sweden, female patients less often received surgery than males (58.6% vs. 78.7%, $P < 0.001$).[53] These registry studies added to the understanding of sex differences in treatment of AAA and outcomes after repair, and showed that more well-designed sex-specific research is essential.

Use outside of IFU

Patients treated with EVAR outside the Instructions For Use (IFU) criteria for the available stent grafts are not included in RCTs. This highlights the importance of registry data to analyze the performance of endografts in the general population, as they are being used currently. Registry studies showed that a high proportion of patients undergo EVAR outside of the IFU. When using a conservative definition of device IFU, 42% of patients met the criteria and even when using the most liberal definition of device IFU, only 69% met the criteria and suggested they may be more prone to sac enlargement.[54] However, long-term all-cause mortality and aneurysm related mortality were unaffected by IFU adherence in another study.[55] More data with more granular details of specific IFU criteria are clearly needed to define the appropriate role of EVAR outside of the manufacturers IFU

Geographic variation

Registries combining data from different countries such as Vascunet and the ICVR, or registries differentiating between regions such as the VQI, can provide essential information for identifying best practices or regions where quality improvement is needed. Large variation in patient selection for elective EVAR, including aneurysm size and patient risk profile is seen.[56] Use of EVAR as compared to open repair (Range: 28% in Hungary - 79% in the US (P<0.01)) and treatment of patients over age 80 (Range: 12% of all patients in Hungary to 29% in Australia (P<0.01)) also significantly vary between countries.[12] A potential contributor to this variation is the different healthcare reimbursement models, such that countries with a fee-for-service system more commonly operate at a smaller aneurysm size and on older patients (Figure 7).[12]

Analysis of variation between regions or countries can also show geographical discrepancies and potential areas for quality improvement. In a study comparing outcomes in several European countries, mortality after EVAR was initially significantly worse in the United Kingdom compared to Sweden. However, with increasing uptake of EVAR combined with centralization of care in England, mortality rates decreased, and after 2007, no difference could be found between the two countries (Figure 8).[57] Also, a Vascunet comparison of outcomes after ruptured AAA showed lower perioperative mortality in centers with a primary EVAR approach and those with higher case volume for open repair.[32]

Even within a country, patient selection and outcomes can vary widely between regions. VQI data from the US showed significant variations in patient selection between regions.[58] When looking at outcomes after AAA repair, several regions did not meet in-hospital mortality benchmarks from the SVS guidelines (range, 0%-7%; P=.55).[59] Awareness of these discrepancies is essential and should prompt changes in management and potentially regionalization of care for open AAA.

Treatment of ruptured AAA

Registry data of Malmö (Sweden) from 1993 highlighted the poor outcomes for ruptured AAA, with 50% operative mortality and 85% overall mortality.[60] While early RCT results did not show any advantage in the treatment of ruptured AAA using EVAR over open repair, Medicare research showed increasing utilization of EVAR over time with decreased EVAR and overall mortality. No increase in mortality with open repair over time was seen, suggesting the trend was most likely due to the utilization of EVAR with its lower operative mortality.[61] A recent study using NIS data showed that EVAR became the dominant treatment module for ruptures AAA repair in 2014.[62] When comparing ruptured AAA management between countries, it was observed that when aneurysm repair was offered to a greater proportion of patients with ruptured AAA, in-hospital mortality was significantly lower.[63] Also, centers with an EVAR-first approach or high open repair case volumes showed lower perioperative adverse outcomes.[32] Overall rupture rates with and without repair declined over time and is likely due to a combination of declining AAA prevalence; treatment of elderly patients with elective EVAR who previously would have been deemed unfit for repair when open surgery was the only option; and improved medical management.[18,64,65] However, ruptured AAA rates in female patients declined in Finland but did not decline over time in Sweden.[53,64]

Rare diseases

The research on uncommon vascular conditions such as endograft infection, internal iliac aneurysms or mycotic aneurysms primarily consists of case reports and small patient series. However, the large patient numbers of registries enable analysis of these rare diseases. The Vascular Low Frequency Disease Consortium (VLFDC) allows centers world-wide to contribute de-identified patient data and study rare vascular diseases. This provides a platform to improve the quality and enables studies of rare diseases. For example, a rare but highly morbid complication of EVAR is aortic endograft infection. A study using data from the VLFDC showed the high morbidity (35%) and mortality (11%) of this complication and enabled the comparison of treatment strategies. Results suggested that the recommended management was surgical excision and that autogenous reconstruction was preferred over prosthetic graft replacement when possible.[66]

Similarly, even though internal iliac aneurysms are rare, the high rupture and mortality rates of internal iliac aneurysms make the understanding of their natural history and the adequate patient selection for surgical treatment essential. Through an international collaboration of vascular registries, Laine et al could study a large series of ruptured internal iliac aneurysms and showed that it was probably safe to increase the repair threshold from 3cm to 4cm.[67] Another international registry study looking at mycotic aneurysm treatment showed that EVAR is feasible with good results in the near term,[68] and in a Swedish nationwide study using propensity score matching it was shown that EVAR for mycotic AAA was associated with a significantly higher short-term survival in comparison with open repair, with similar incidence of late serious infection-related complications and reoperations.[69] However, in young and fit patients with mycotic aneurysm, in situ reconstruction with autologous graft seems to be the best solution as in yet another multicenter registry-based study, which collected data from 56 patients with mycotic aneurysms from 6 countries, showed that after reconstruction of mycotic aneurysms with biological grafts, mortality was low (3/56) and reinfection rate at 26 months was zero.[70]

Future challenges and breakthroughs

Although several registry-based studies have improved the quality of care among patients with AAA, registry-based studies can be improved significantly by specific maneuvers which will improve data validity and expand the data crucial to AAA research.

Future breakthroughs in registry research will come from improving registry participations, partnerships with different stakeholders and linkage of data.

The incorporation of registry data as elements in the electronic health records will be an essential breakthrough in registry research. Directly using electronic medical records data will improve the accuracy of the data and standardization of data collection.

An important challenge will be to diminish financial obstacles associated with participating in a vascular registry and therefore potential for bias. Also, harmonization of variable definitions across registries will be essential to advance collaborations and currently presents a challenge for established registries to update data elements.

Through partnerships with different stakeholders and linkage of data, registry data can reach its full potential. An ongoing project linking data from the VQI and Medicare databases (The Vascular Implant Surveillance and Interventional Outcomes Network (VISION) database) combines the clinical, anatomical and procedural granularity from a prospective vascular-specific database with long-term administrative follow-up data to detect re-admissions, re-interventions, and ruptures after AAA repair.

An important shift in the interpretation of vascular registry research will come from the way quality is measured. Although mortality is the most common outcome measure in current studies and is likely appropriate for measuring quality after open AAA repair, it does not adequately discriminate high from low quality EVAR. Other important quality indicators such as rate of conversion from EVAR to open repair, late rupture, adherence to IFU, follow-up compliance, endoleak rates, or reinterventions should be considered when evaluating EVAR but the appropriate metrics are yet to be defined. Therefore, collection of these outcomes by registries and determination of the appropriate quality indicators will be essential.

Conclusion

The continuous and rapid technological progress in aortic surgery and the exponential growth in knowledge has caused dramatic changes in the management of patients with AAA. Furthermore, registries provide data to study the changes in epidemiology, treatments and outcomes over time. By understanding the strengths and limitations of vascular registries, researchers can use them to improve quality, to develop management guidelines, and to compliment outcomes from RCTs.

Conflict of interest statement

Dr Schermerhorn has received consulting income from Abbott, Cook, Endologix, Medtronic, and Philips.

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Name	Coverage
Administrative datasets	
Medicare	US population of Medicare beneficiaries (>65 years)
Hospital episode statistics	National Health Service (NHS) hospitals in England
National inpatient sample	20% of all discharges from US community hospitals
Quality improvement registries	
Swedvasc	National coverage for vascular surgery in Sweden
EUROSTAR	Participating centers in Europe
SVS-VQI*	Participating vascular centers in US
International registry collaborations	
Vascunet	European and Australasian national and regional vascular registries
ICVR#	Transatlantic collaboration of vascular registries (SVS-VQI and Vascunet)

*SVS-VQI: Society for vascular surgery quality improvement registry; ICVR: International consortium of vascular registries.

	1994-1999	2000-2005	2006-2011	2012-2016
Proportion of repairs with EVAR				
Intact AAA	6%	19%	47%	63%
Ruptured AAA	1%	5%	19%	37%
30-day mortality				
Intact EVAR	3.4%	3.9%	1.2%	1.1%
Intact open repair	6.2%	7.7%	3.1%	2.5%
Ruptured EVAR	68.8%	31.1%	20.6%	21.2%
Ruptured open repair	45.6%	47.3%	30.4%	28.1%

EVAR=Endovascular aneurysm repair. AAA=Abdominal aortic aneurysm. Source: Swedvasc reports and *Bergqvist D, Mani K, Troëng T, Wanhainen A. Treatment of aortic aneurysms registered in Swedvasc. Gefasschirurgie. 2018;23(5):340–5.*

19-0800 figure legends

Figure 1: Risk-adjusted analysis of volume impact on in-hospital mortality after EVAR and open repair of intact and ruptured abdominal aortic aneurysms using ICVR data.

Reproduced from Scali ST, Beck AW, Sedrakyan A, Mao J, Venermo M, Faizer R, et al. Hospital Volume Association With Abdominal Aortic Aneurysm Repair Mortality: Analysis of the International Consortium of Vascular Registries. Circulation. 2019 Oct 8;140(15):1285–7.

Figure 2: Ruptured AAA perioperative mortality and EVAR % per center and volume in the Vascunet registry.

Reproduced from Budtz-Lilly J, Björck M, Venermo M, Debus S, Behrendt C-A, Altreuther M, et al. Editor's Choice – The Impact of Centralisation and Endovascular Aneurysm Repair on Treatment of Ruptured Abdominal Aortic Aneurysms Based on International Registries. European Journal of Vascular and Endovascular Surgery. 2018 Aug;56(2):181–8.

Figure 3: Mortality Risk Score after EVAR or open repair using Medicare data.

Reproduced from Giles KA, Schermerhorn ML, O'Malley AJ, Cotterill P, Jhaveri A, Pomposelli F, et al. Risk prediction for perioperative mortality of endovascular versus open repair of abdominal aortic aneurysms using the Medicare population. J Vasc Surg Off Publ Soc Vasc Surg Int Soc Cardiovasc Surg North Am Chapter. 2009 Aug;50(2):256–62.

Figure 4: Ruptured AAA frequency in relation to patients' age in Finland.

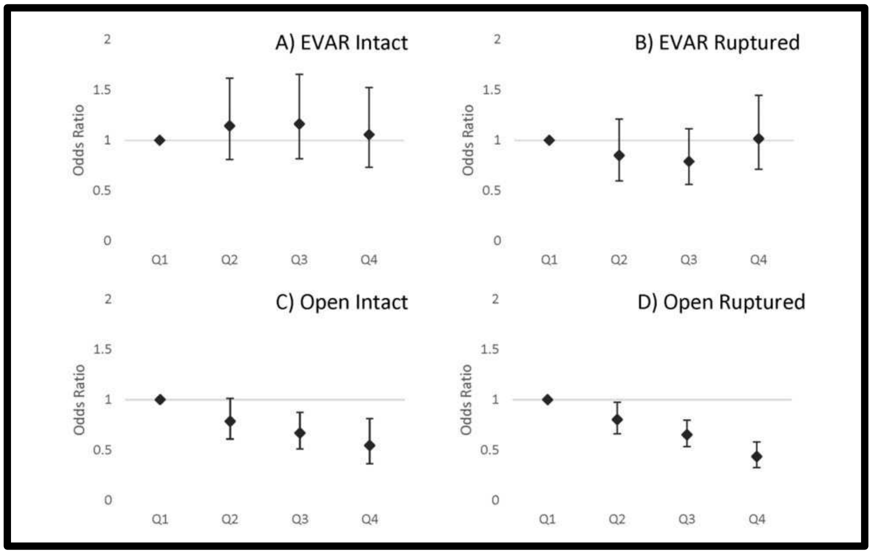
Reproduced from Laine MT, Vänttinen T, Kantonen I, Halmesmäki K, Weselius EM, Laukontaus S, et al. Rupture of Abdominal Aortic Aneurysms in Patients Under Screening Age and Elective Repair Threshold. Eur J Vasc Endovasc Surg. 2016 Apr 1;51(4):511–6.

Figure 5: Survival after EVAR and open repair, per age group in Medicare data.

Reproduced from Schermerhorn ML, Cotterill P. Endovascular vs. Open Repair of Abdominal Aortic Aneurysms in the Medicare Population. N Engl J Med. 2008;11.

Figure 6: Distribution of ruptured repair as a function of aortic diameter (A) and aortic size index (B) using VQI data.

Reproduced from Lo RC, Lu B, Fokkema MTM, Conrad M, Patel VI, Fillinger M, et al. Relative importance of aneurysm diameter and body size for predicting abdominal aortic aneurysm rupture in men and women. J Vasc Surg. 2014 May;59(5):1209–16.


A) EVAR Intact
B) EVAR Ruptured
C) Open Intact
D) Open Ruptured
Odds Ratio
2
1.5
1
0.5
0
Q1
Q2
Q3
Q4

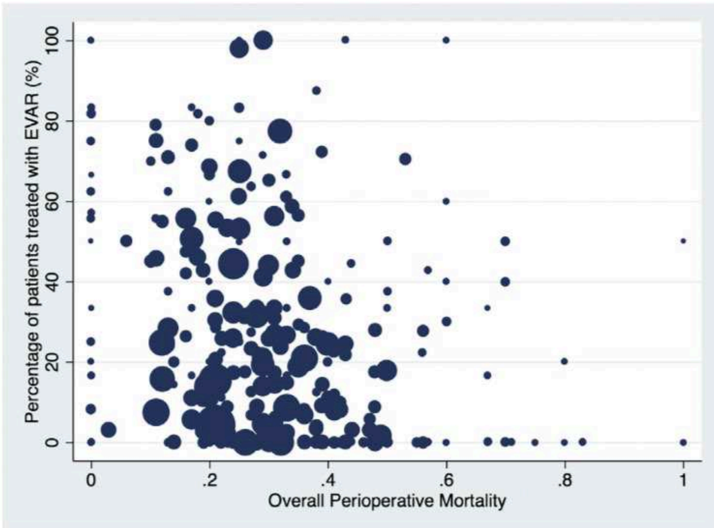


Figure 2. Bubble chart depicting the overall peri-operative mortality and the percentage of EVAR per centre on the x and y axis, respectively, while the size of each bubble represents the relative number of patients treated at each centre for 2010—2013.

Risk Factor	**Score**
AGE	
> 80	+ 11
76–80	+ 6
71–75	+ 1
Female	+ 4
Renal failure	
Dialysis dependent	+ 9
No dialysis	+ 7
CHF	+ 6
PVD or CBVD	+ 3

Total Score =

Risk	**Score Range**	***Open* Predicted Mortality**	***EVAR* Predicted Mortality**
High	> 11	> 6.3%	> 2%
Medium	3–11	2.8–6.3%	0.9–2.0%
Low	< 3	<2.8%	< 1%

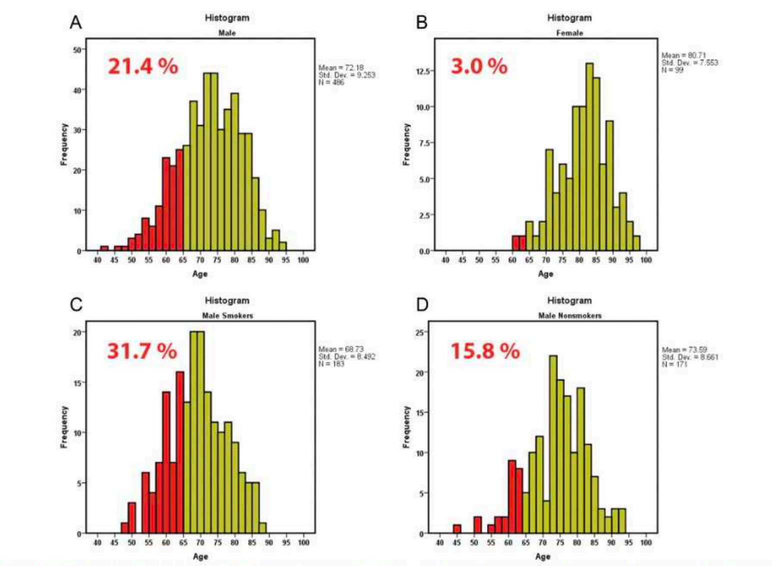
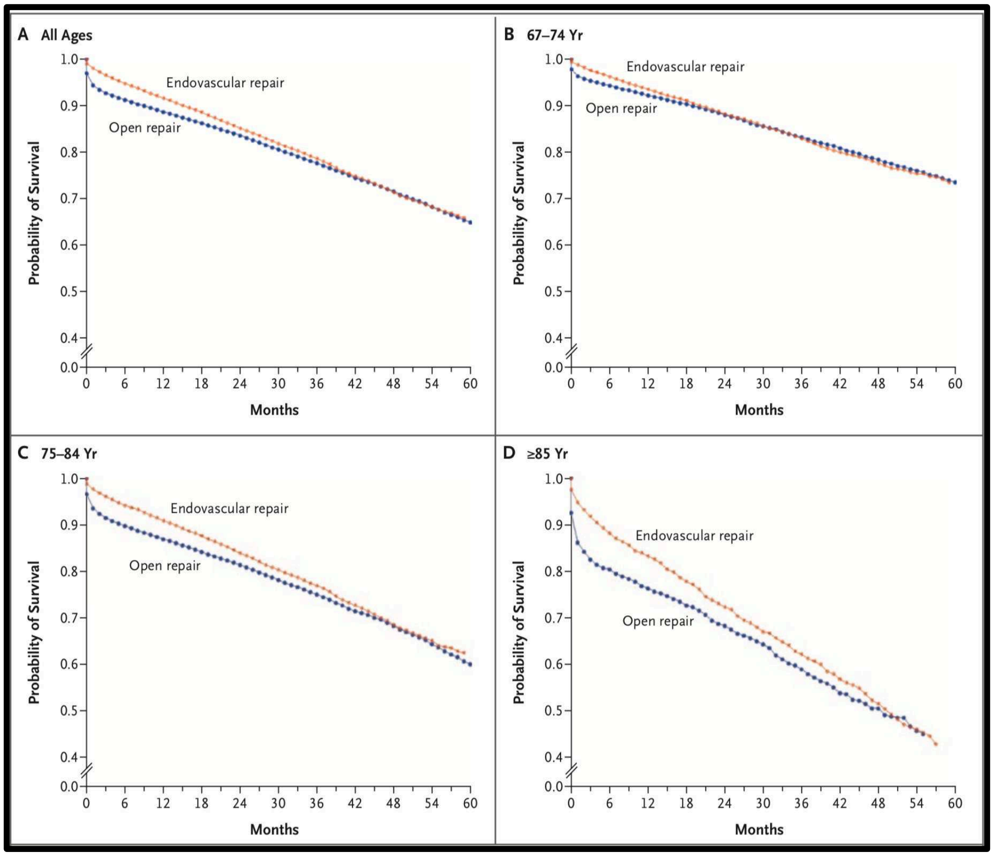
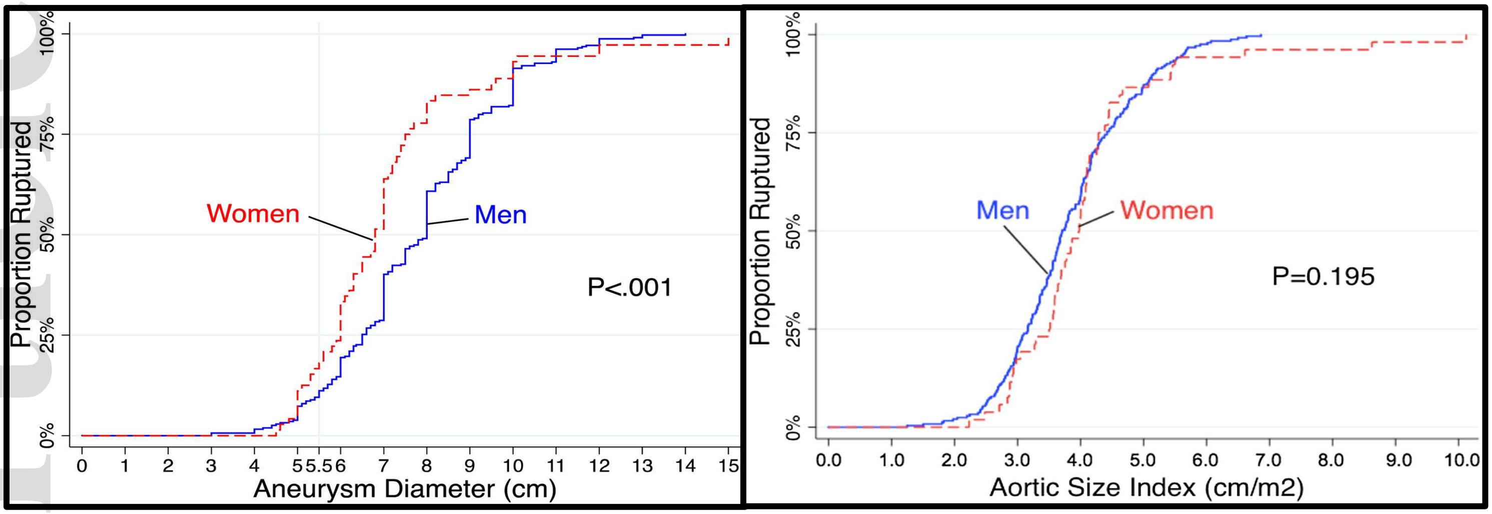
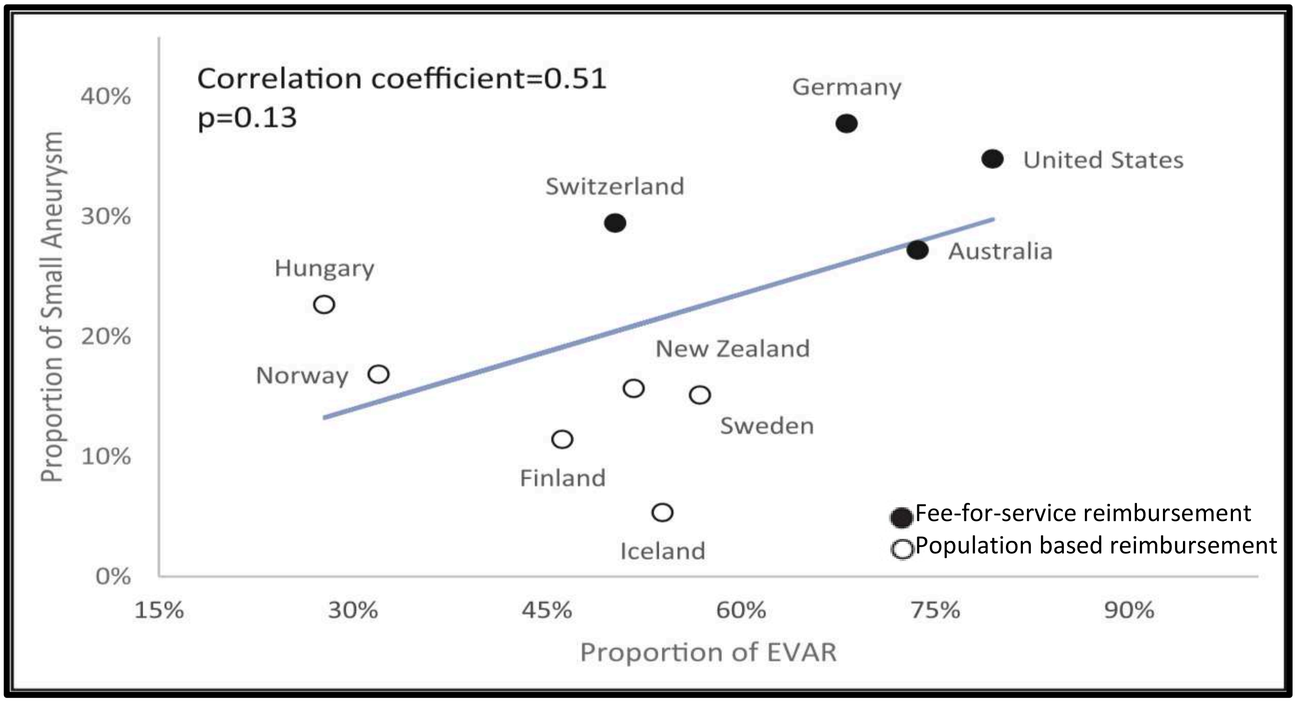


Figure 1. Histogram image showing the number of ruptured abdominal aortic aneurysm patients in relation to patient age. Red columns correspond to patients under 65 years of age with corresponding percentages: (A) men; (B) women; (C) male smokers; (D) male non-smokers.

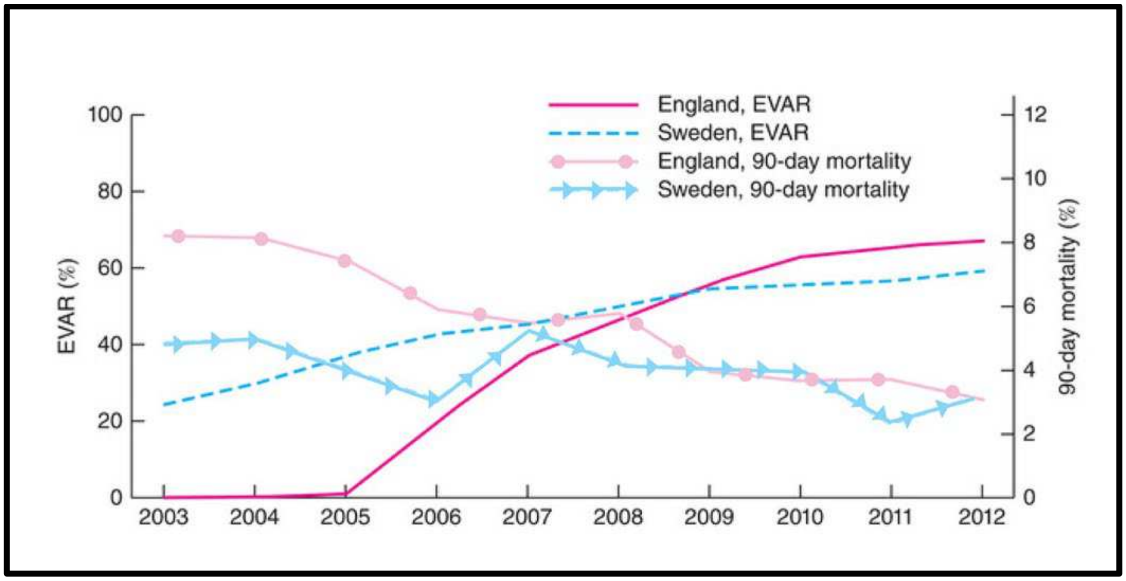

A All Ages
Endovascular repair
Open repair
Probability of Survival
Months
B 67–74 Yr
Endovascular repair
Open repair
Probability of Survival
Months
C 75–84 Yr
Endovascular repair
Open repair
Probability of Survival
Months
D ≥85 Yr
Endovascular repair
Open repair
Probability of Survival
Months



Proportion Ruptured
0%
25%
50%
75%
100%
Women
Men
P<.001
0
1
2
3
4
5
5.5
6
7
8
9
10
11
12
13
14
15
Aneurysm Diameter (cm)
Proportion Ruptured
0%
25%
50%
75%
100%
Men
Women
P=0.195
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Aortic Size Index (cm/m2)



Correlation coefficient=0.51
p=0.13
Germany
United States
Switzerland
Australia
Hungary
Norway
New Zealand
Sweden
Finland
Iceland
Fee-for-service reimbursement
Population based reimbursement
Proportion of Small Aneurysm
40%
30%
20%
10%
0%
15%
30%
45%
60%
75%
90%
Proportion of EVAR


England, EVAR
Sweden, EVAR
England, 90-day mortality
Sweden, 90-day mortality
EVAR (%)
90-day mortality (%)
100
80
60
40
20
0
12
10
8
6
4
2
0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012